Collaborative Proposal to Extend ONR YIP research with BRC Efforts

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LONG-TERM GOALS

The long-term scientific goals of this research project are:

1. To develop an understanding of how some sources of error affect ocean predictability.
2. To gain experience and develop ideas for the limitations to the predictability of oceanic processes.

OBJECTIVES

The primary objectives of this project are: (i) to undertand the importance of model uncertainty; (ii) to assess the influence of uncertainty on predictability; and (iii) to collaborate and learn from fellow BRC projects.

APPROACH

The ocean contains energy at many scales from planetary (megameters) down to small turbulent mixing (centimeters). The dominant range of energy exists in the mesoscale; however, there are some regional seas where energy at other scales are of similar strength. Regions such as Hawaii, South China Sea, Philippine Sea, and others contain significant baroclinic internal wave energy generated by the conversion of the barotropic tides. The energy of these internal waves interacts with the mesoscale with higher energy modes dissipating quickly into the background flow leaving predominantly mode-1 baroclinic waves. The interaction between the mesoscale and internal waves is an active area of research in the ocean, and is not well understand how energies cascade between the two scales.

Furthermore, internal waves often heave the thermocline by as much as 100m as they propagate by greatly affecting *in situ* observations from platforms such as gliders, acoustic tomography, moorings, etc. For fixed observations with frequent enough observations, these signals are easily identified; however, in non-traditional observations, the internal wave signals typically cannot be extracted. For instance, as gliders pass through time and space, there is a smearing of the internal wave energy. Likewise, heaving of the density surfaces by internal waves changes the propagation of sound impacting tomographic measurements. The surface bounce of internal waves has a random

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phase due to density variations in the background stratification, which impacts high-frequency radar measurements adding significant uncertainty in the estimate of the surface flow.

In both the dynamical impacts and the effect upon observations, internal waves are a significant source of uncertainty in the ocean. To improve forecasts of the ocean circulation, we must understand how internal waves impact both the mesoscale and observations to better quantify the uncertainty introduced by internal waves. As more ocean models implement tides, particularly in the regional seas, it is important to reduce the model uncertainty due to these tidally induced signals.

The ocean model used in this research is the ONR-funded Regional Ocean Modeling System (ROMS): a free-surface, hydrostatic, primitive equation ocean model discretized with a terrain following vertical coordinate system. The model has multiple sub-gridscale parameterizations of vertical mixing along with many options for open boundary conditions. Time-splitting of barotropic and baroclinic motions enables efficient time integration. ROMS has been successfully used to model many regions of the world ocean (see `http://www.myroms.org/papers`) and is a widely used community resource.

WORK COMPLETED

During the current reporting period, we have worked to understand the impact of internal waves on predictability of regional oceans of Hawaii and the North Philippine sea. Along with a graduate student, Colette Kerry, who is supported under ONR #N00014-09-1-0939, we have performed adjoint sensitivity experiments to identify how the mesoscale can change the generation and propagation of internal waves. In conjunction with my Young Investigator award, we are working to understand how internal waves affect observations in the ocean. Two papers are currently in preparation: Powell et al. (2011); Kerry and Powell (2011).

In the year one report, we noted the work to understand the length scales of variability in collaboration with another BRC member, Ralph Milliff. This paper (Matthews et al., 2011) was published in 2011.

RESULTS

As part of the ongoing efforts of my Young Investigator Program award (ONR #N00014-09-1-0939) as well as the operational NOAA Integrated Ocean Observing System, we have built an operational, real-time assimilation and prediction system for the main Hawaiian islands. This system provides a foundation laboratory for research into state estimation and predictability. In support of these efforts, we have worked to understand the impact of the internal waves on our assimilation and prediction.

Using the Hawaii experiment, we have run an adjoint sensitivity experiment to understand how the mesoscale affects the conversion of energy from the barotropic to baroclinic tides. Around Hawaii, nearly 3GW of energy is converted by theh M_2 tide at Kaena Ridge between Oahu and Kauai. Focussing upon this ridge, but considering the significant semidiurnal tides (M_2, S_2, N_2), we determined the contribution of the oceanic flow to the conversion. As shown in Figure 1, the sensitivity of baroclinic conversion on the southern flank of the ridge to salt shows that decreasing the density will increase the conversion (by changing the pressure perturbation) with the opposite effects on the opposite side of the ridge. On the opposite side, a change would affect the conversion

of energy M_2 energy as it propagates southward; hence, more energy is available for conversion on the southern flank.

Similarly, we are working to characterize the internal wave field in the Northern Philippine Sea as part of the ΨEx funded by ONR Acoustics. We have examined the interaction between the internal tides generated at the Luzon Strait with those generated by the Mariana island arc (Figure 2). In addition, we have examined the adjoint sensitivity of the Luzon Strait to the background flow. We began with a high-resolution, quiescent ocean forced only by the barotropic tides. As shown in Figure 2, the generation of internal waves is most sensitive to perturbations in the density field along the ridge (recall there is no background flow in this example). We are currently implementing a full model of lower-resolution but including the full, time-evolving ocean to understand the interaction of the mesoscale to the generation.

IMPACT/APPLICATIONS

Internal Waves and the associated mixing is one of the research priorities for the oceanic community. As scales of models improve, internal waves become an important factor. In deeper oceans, the non-hydrostatic component of internal waves is negligible, which means that internal waves are present and crucial to the state estimation in existing models. As models move into very shallow waters, only non-hydrostatic models would be capable of resolving internal waves; however, in the present, it is important to reduce the uncertainty from tidally induced internal waves before stepping down in scale.

TRANSITIONS

One paper is in final preparation and presentations will be made at the International Adjoint Workshop to be held in Oct., 2011. In addition, one PhD student, Colette Kerry, has been performing the adjoint work in the Philippine Sea, training a future community member in adjoint-based methods and later data assimilation.

RELATED PROJECTS

This project is collaborating with the following ONR supported projects:

- "A community Terrain-Following Ocean Model (ROMS)", PI Hernan Arango, grant number N00014-08-1-0542.

REFERENCES/PUBLICATIONS

C. Kerry and B. S. Powell. Interacting m_2 internal tides in the north philippine sea. *J. Phys. Oceanogr.*, in prep, 2011.

D. Matthews, B. S. Powell, and R. F. Milliff. Dominant Spatial Variability Scales from Observations around the Hawaiian Islands. *Deep-Sea Res., Part I*, 58:979–987, 2011.

B. S. Powell, I. Janeković, G. S. Carter, and M. A. Merrifield. Sensivity of internal tide generation to the mesoscale. *Geophys. Res. Let.*, in prep, 2011.

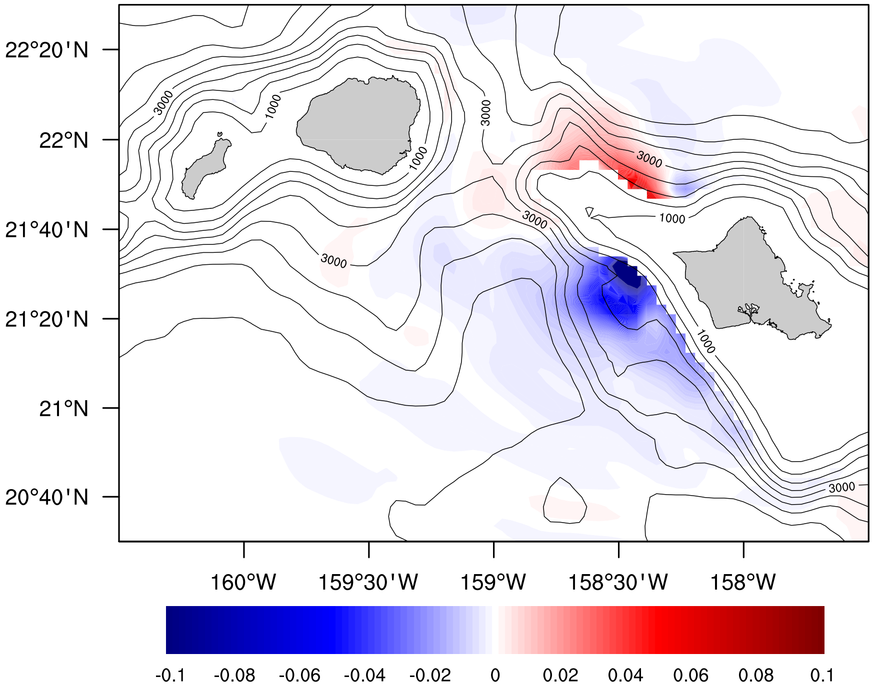

Figure 1: Mean sensitivity of Baroclinic tide conversion to salt.

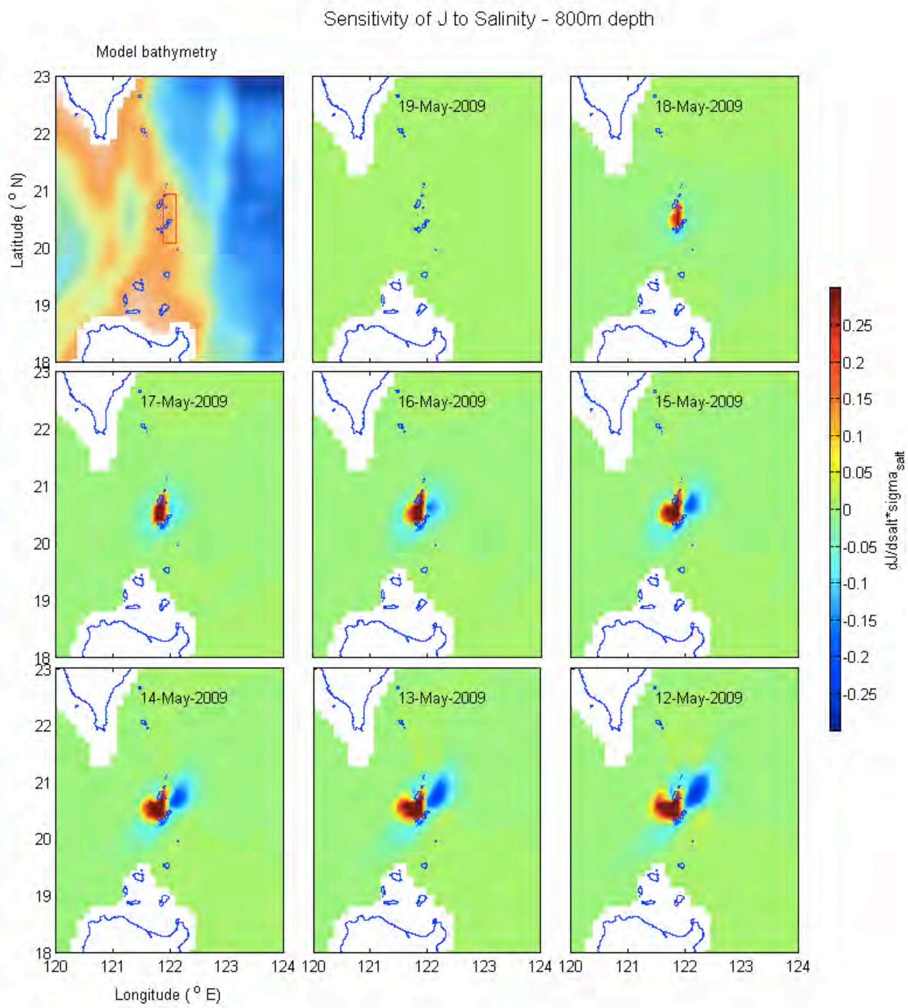

Figure 2: Sensitivity of Internal Wave criticality condition to salt over four days. Notice that even on the opposite side of the ridge, a decrease in criticality (and a decrease in the energy conversion on the opposite side) leads to an increase in the criticality on the eastern flank. Likewise, a decrease in density on the eastern flank increases the criticality.